CDF Physics

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Fermilab

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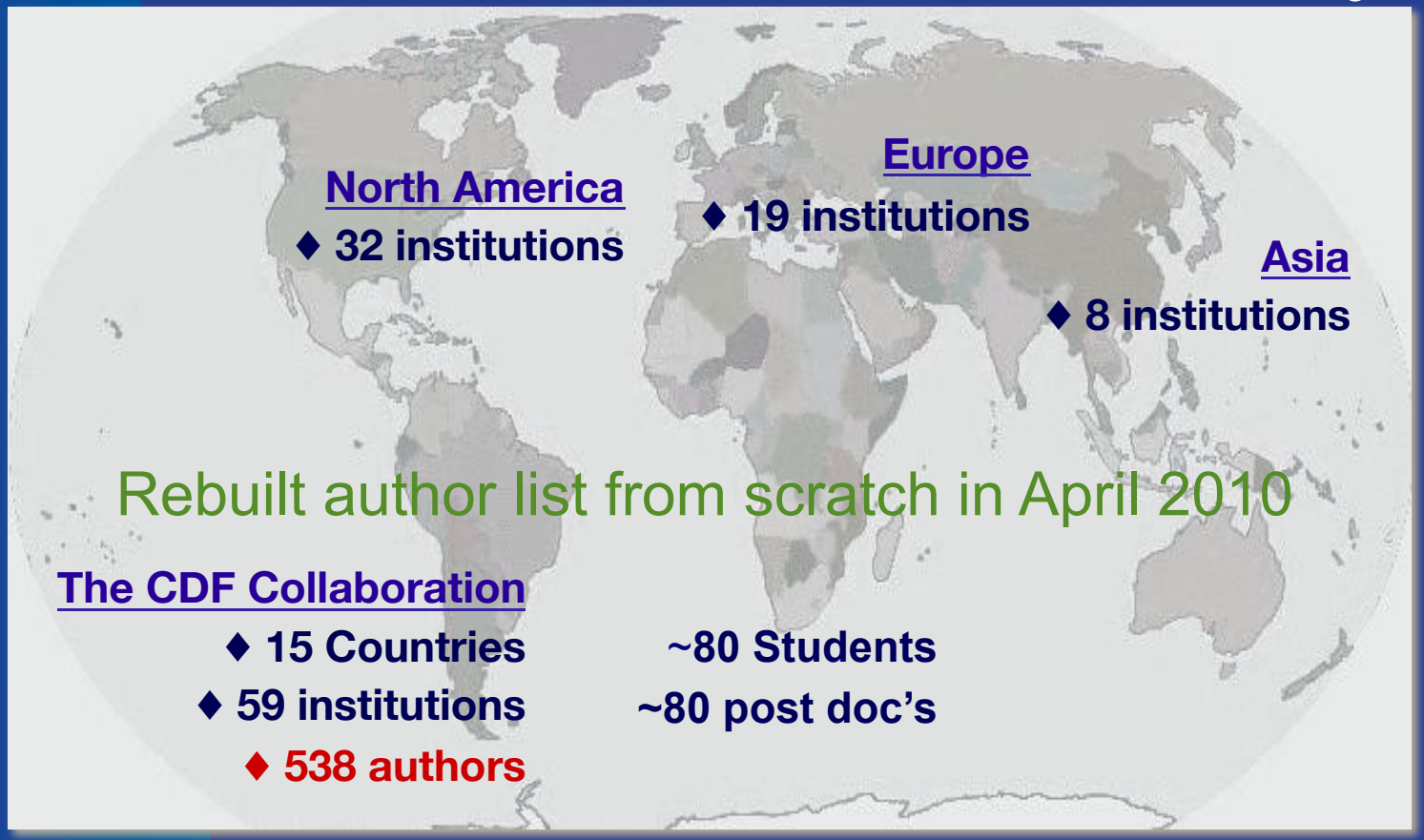
U.S. DEPARTMENT OF ENERGY

Fermilab

The CDF Collaboration as of Today



North America
- 32 institutions

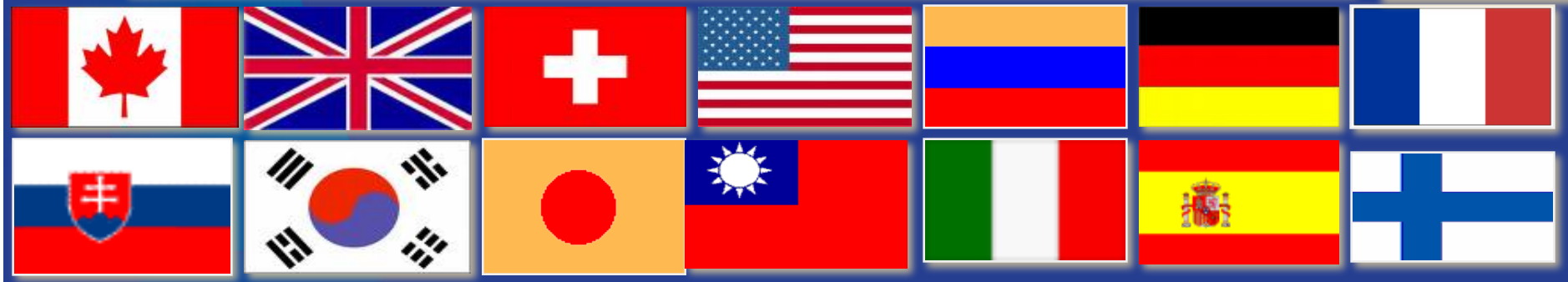
Europe
- 19 institutions

Asia
- 8 institutions

Rebuilt author list from scratch in April 2010

The CDF Collaboration
- 15 Countries
- 59 institutions
- 538 authors

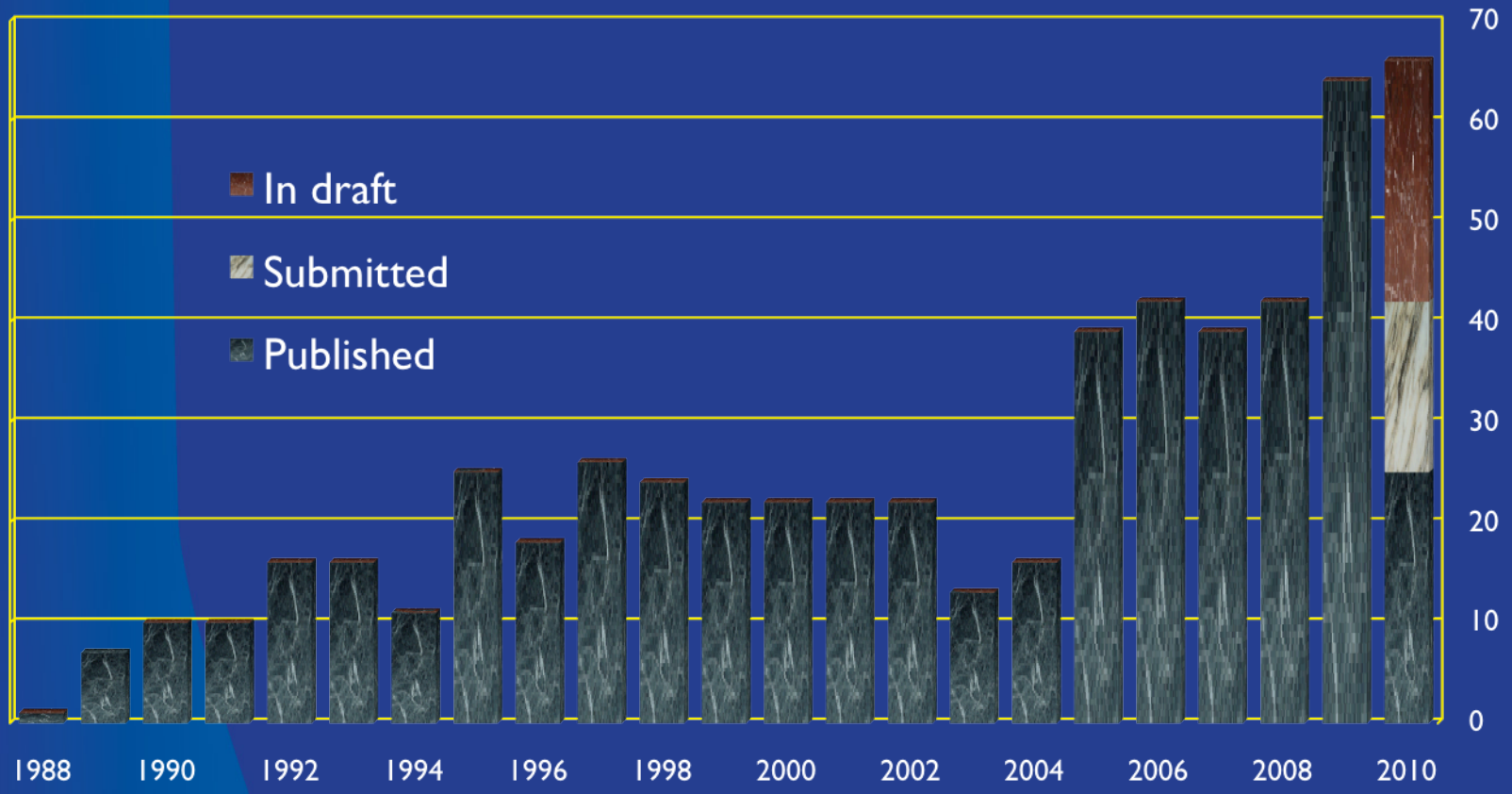
~80 Students
~80 post doc's



Why, in April 2010, did 538 authors continue on CDF ?

- Many fundamental questions of particle physics can be answered by CDF
  - Are there new particles & forces beyond the SM ?
  - Is there a Supersymmetry ? Extra dimensions ?
  - Can we produce and study dark matter ?
  - Can rare decays bring new physics to view ?
  - Are there differences between matter and antimatter ?
  - New sources of CP violation ? CPT violation ?
  - Does SM describe electroweak / strong physics at high energies ?
  - Can we measure all SM backgrounds to new physics ?
  - Is the most massive SM particle, the top quark, special ?
  - Do high order theoretical predictions work ?
  - Do observed quark bound states match theory ?
  - What is the true structure of the proton ?
  - How is electroweak symmetry broken ?
  - Is there a Higgs boson or something else ?

Peer review agrees we are asking the right questions



CDF on track to surpass 2009 banner year !

PhD's Awarded

- 41 awarded since January 2009
- 250 awarded for work on Run II data
- 514 CDF students received PhD's thus far

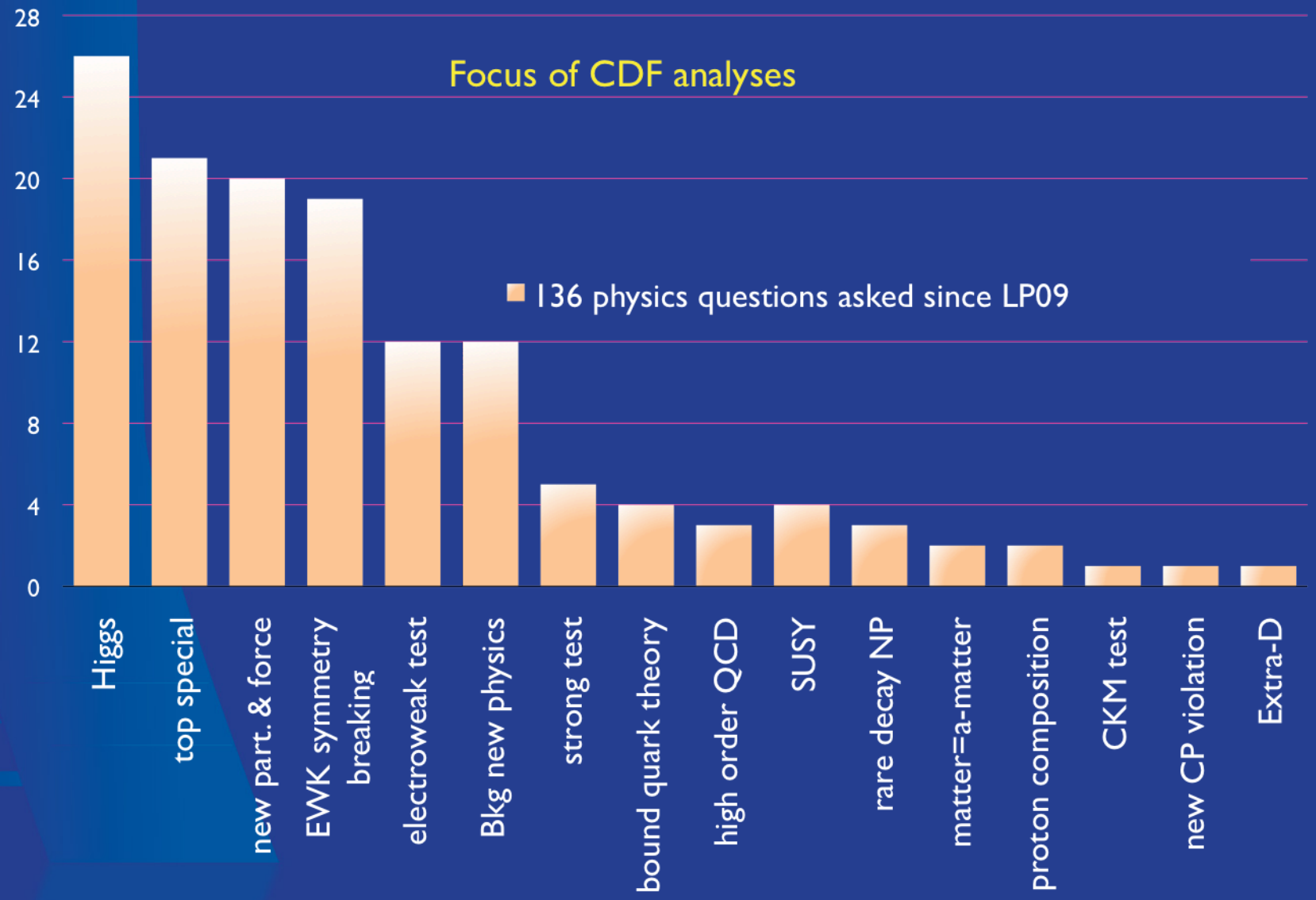
Current CDF physics program

Today, we will show results after Lepton Photon August 2009

> 75 new results ready for ICHEP 2010 !

- Tevatron has delivered 9 fb^{-1}
- 6 fb^{-1} of analyzed data collected up to March 2010 shown today

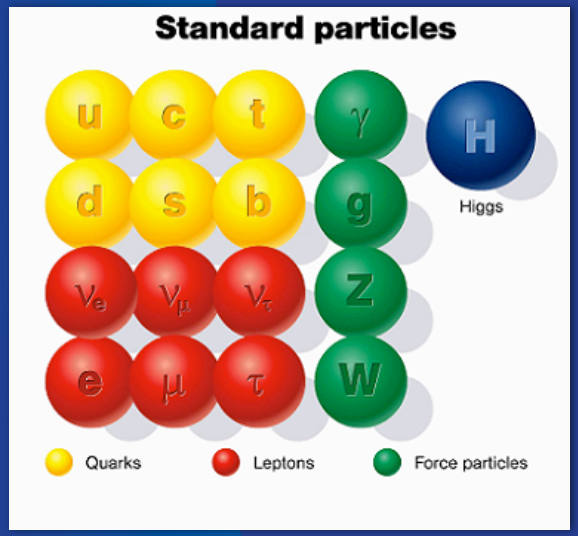
CDF's new results



Outline

- Can't cover all 75 new results
- Will cover some new results focusing on the following important physics questions
  - Can we measure all SM backgrounds to new physics ?
  - Are there new sources of CP violation ?
  - Is the top quark special ?
  - Are there new particles/interactions beyond the SM ?
  - Is there a Higgs boson ?

Can we measure all SM processes which are backgrounds to new physics ?



- New physics signatures tend to have some combination of missing transverse energy (MET), multiple leptons, jets, photons
- Can search for excess of events above SM predictions
  - Need to get correct rate of SM
- Can search for deviant shape indicating a specific signal
  - Need to get correct shape of SM
- Can verify analysis tools used for searches

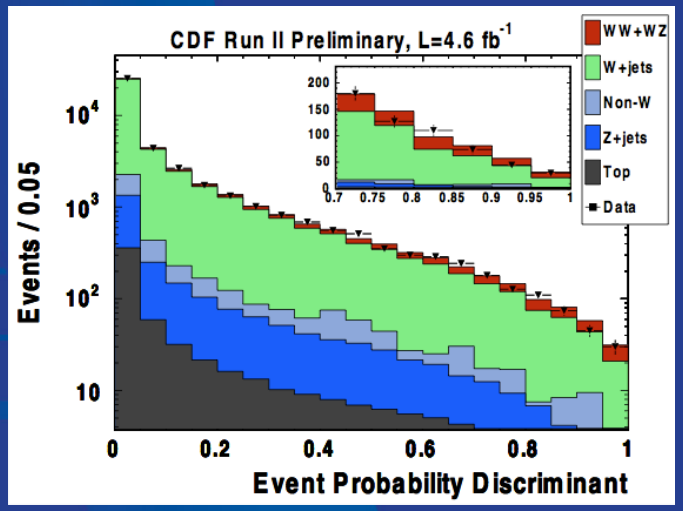
$WZ \rightarrow lll\nu$ $Z\gamma \rightarrow \nu\nu\gamma$ $WW \rightarrow l\nu jj$

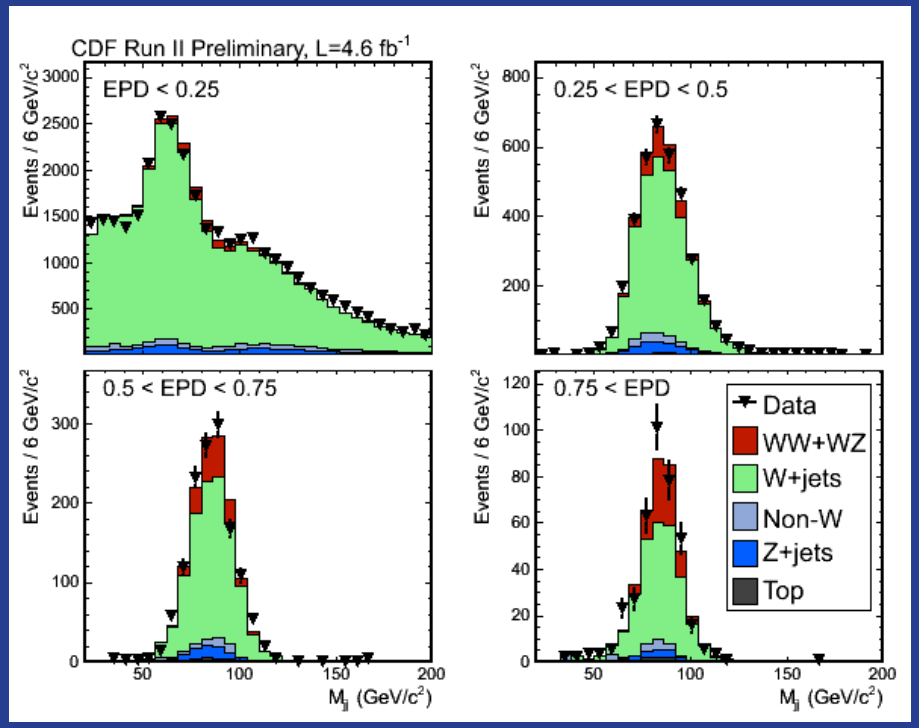
$WZ \rightarrow l\nu bb$ $Z\gamma \rightarrow \mu\mu\gamma$ $\gamma\gamma$ $ZZ \rightarrow llll$

Search for WW/WZ → lνjj

- First observation in 2009
- Background for powerful WH →lνjj Higgs search channel
- Analysis uses likelihood fit of matrix element differential probabilities

Allows precise test of analysis tools used in Higgs analyses

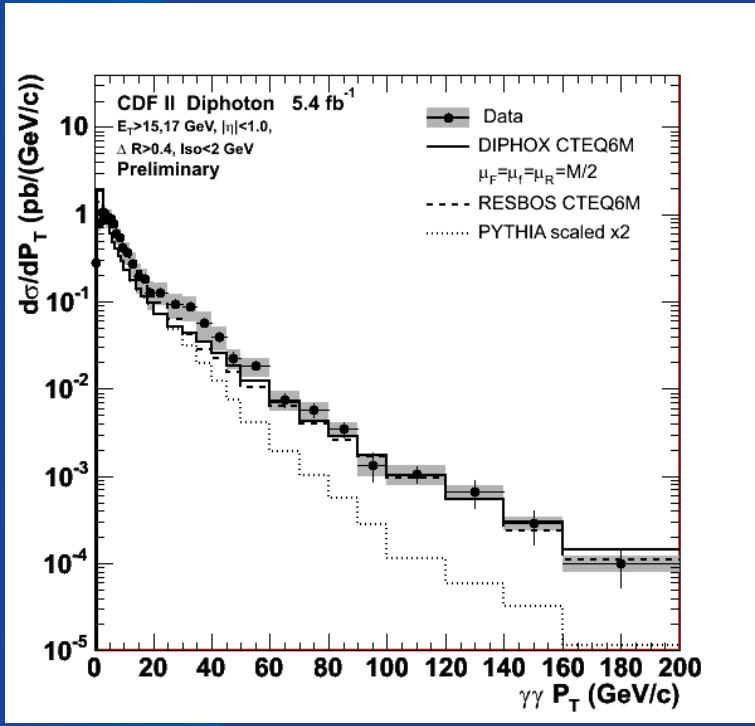


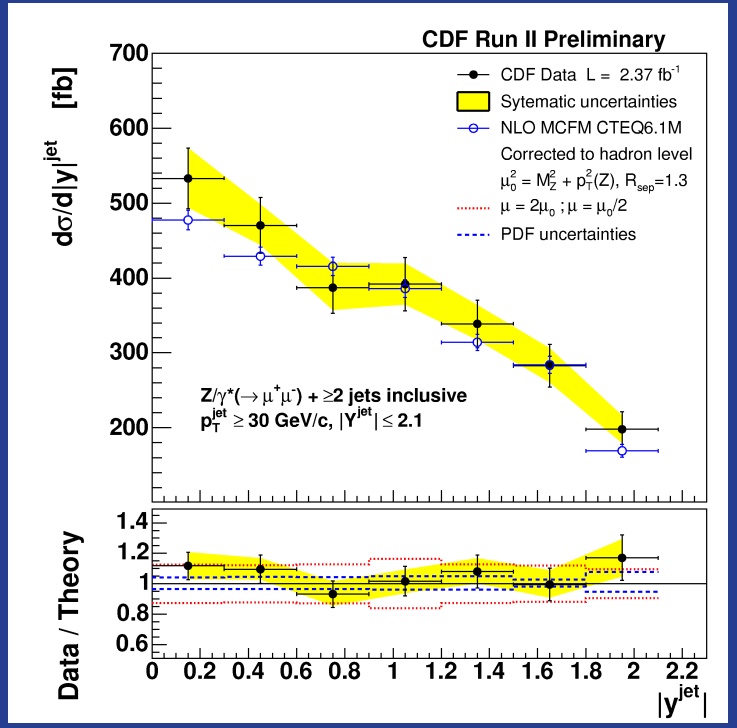


$\sigma(WW+WZ) = 16.5^{+3.3}_{-3.0}$ pb

NLO theory : 15.1 ± 0.8 pb

Some Other Backgrounds to New Physics





Diphoton differential x-section

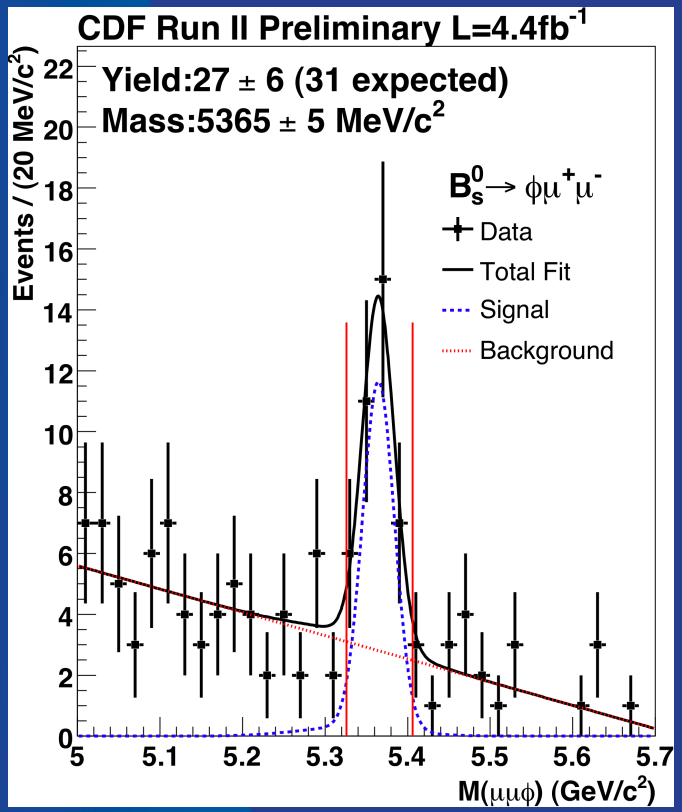
Background to Higgs, gravitons, SUSY

Z+jets differential x-sections

Background to Z+Higgs, MET +jets SUSY searches

Other ways to test for new phenomena

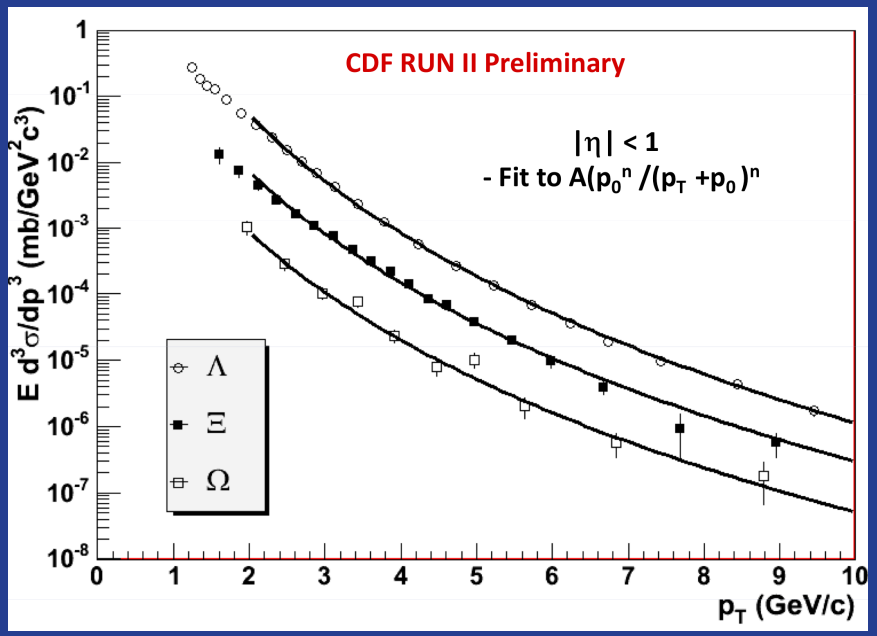
Rare decays



$B_s \rightarrow \Phi\mu\mu$ 1st observation:

FCNC's from BSM physics can enhance rate

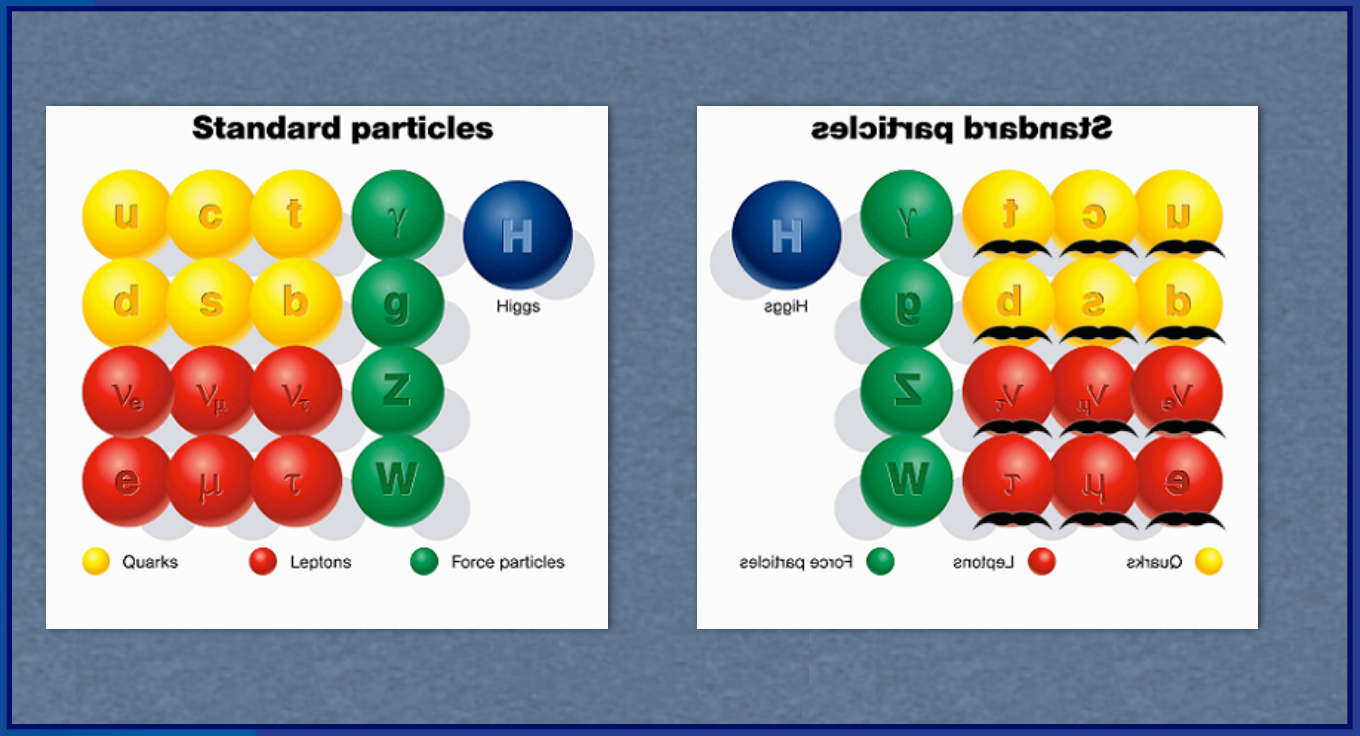
Copious decays



Hyperon differential cross-section:

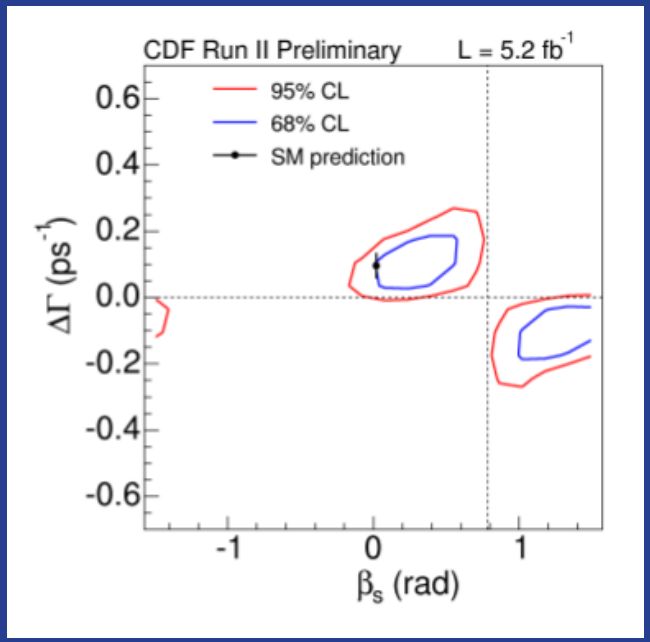
Strange baryons like Ω^-(sss) can be enhanced if Quark-gluon plasma

Are there unexpected CP violation sources ?

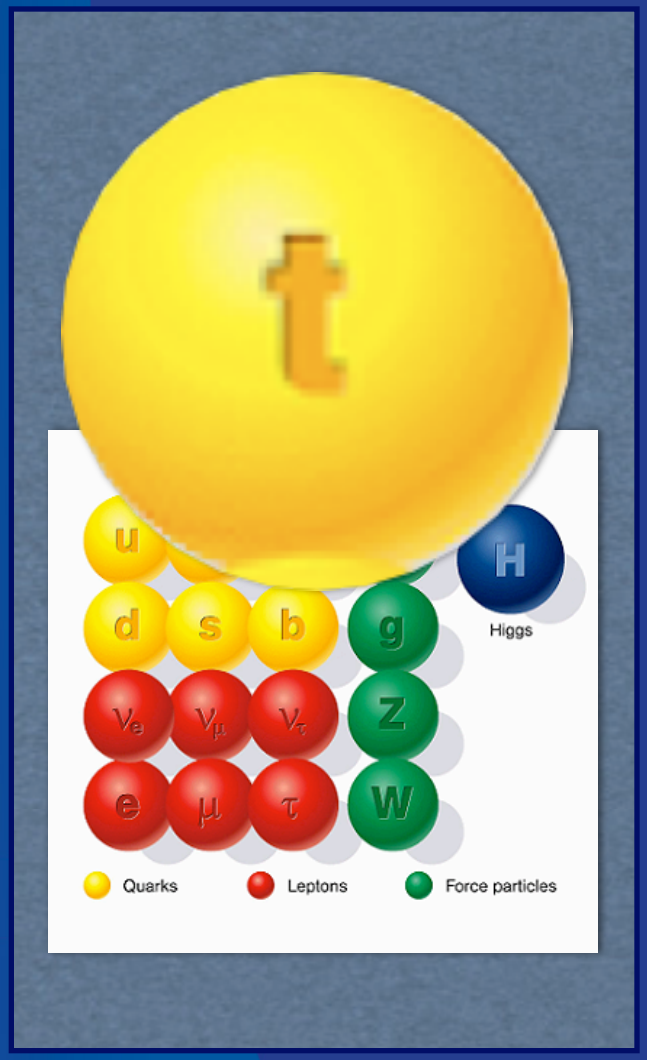


β_s CP violating Phase

- CP violation in B_d system well studied
- But CP violation in B_s recent development
- $B^0_s \rightarrow J/\Psi\ \Phi$ decays
  - SM predicts small CP violating phase β_s
    - Deviation could indicate New Physics
- Previous CDF analyses indicated ~1.5 σ discrepancy with SM
- New result 2 times data and new particle ID tools
  - Result more consistent with SM
  - But also, more consistent with New Physics

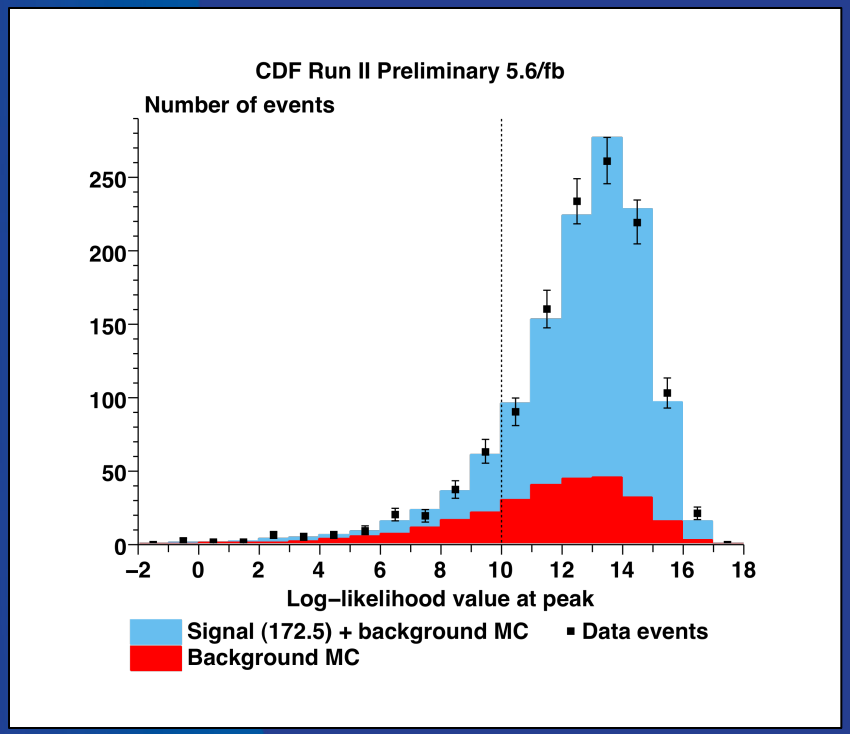


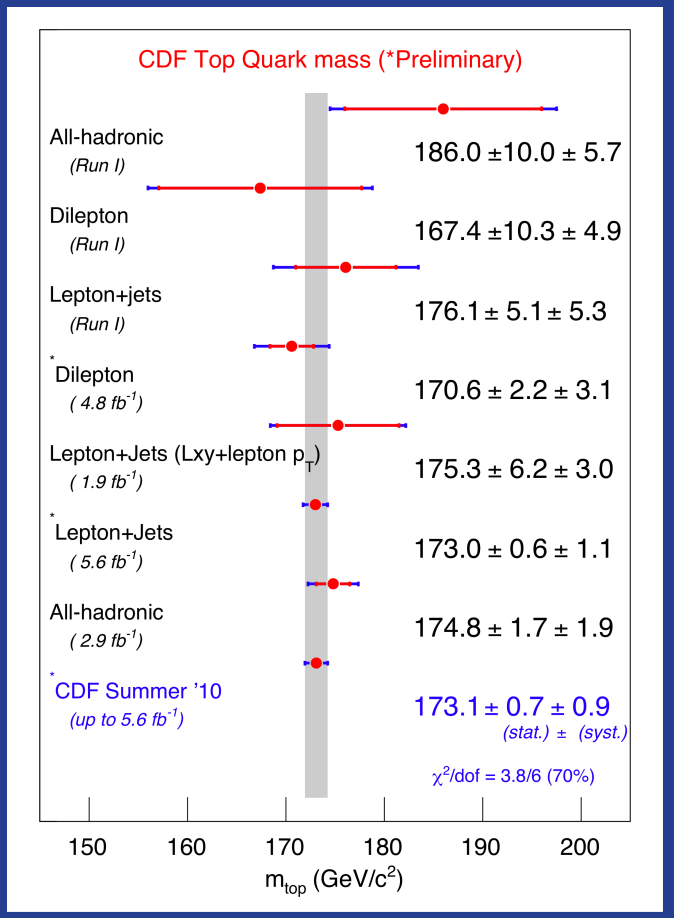
Is the top quark special ?



- Top quark is the heaviest known particle
  - Perhaps involved in electroweak symmetry breaking
- Production and decay test high energy QCD and EWK forces
- Precise top mass constrains Higgs boson mass

Top quark mass



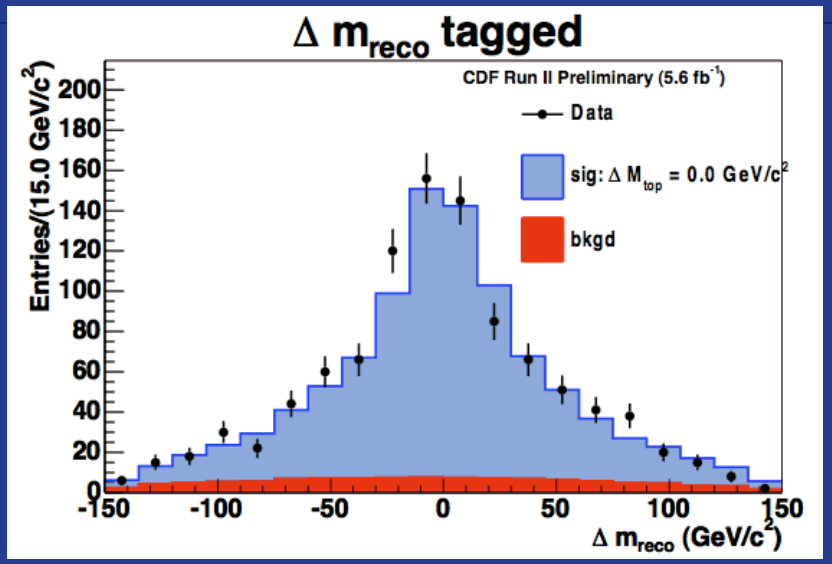


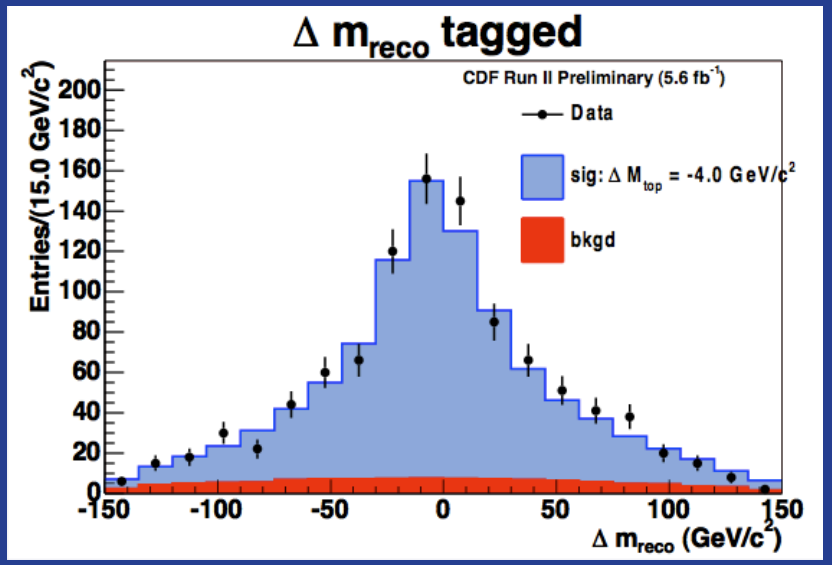
- New CDF 5.6 fb^{-1} top mass measurement
- M_t = 173.0 ± 1.2 GeV (0.7% uncertainty !)
- Individual measurement more precise than 2009 world top mass average

- New CDF 2010 top mass combination ~ 0.65%

Top mass precision can probe new physics

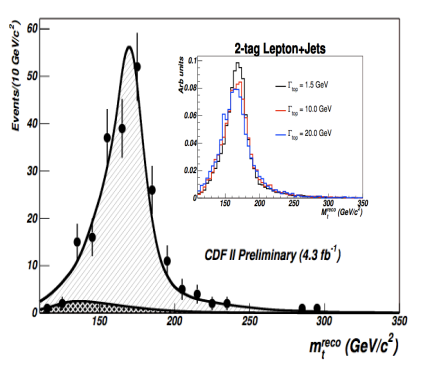
- Mass difference between top quark and anti-top quark ?
  - Test of CPT conservation in top quark sector
- Measured difference
  - $\Delta m_T = 3.3 \pm 1.4_{stat} + 1.0_{sys}$ GeV
  - P-Value = 6%



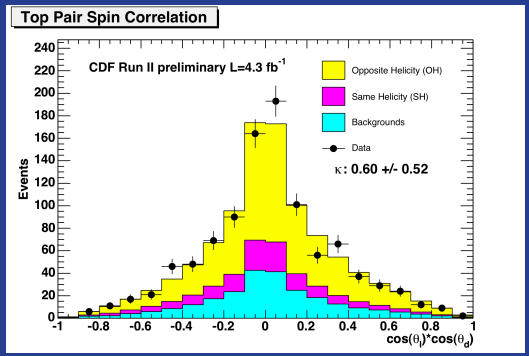


Is the top quark special ?

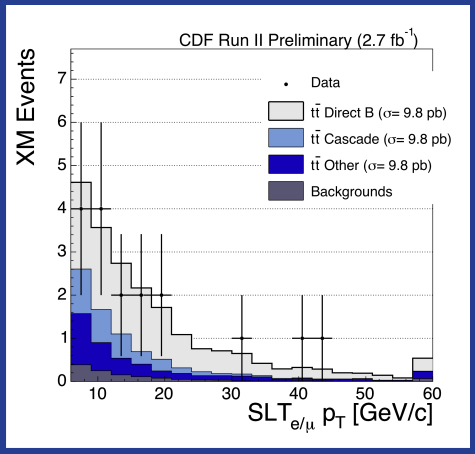
Top Width < 7.5 GeV
@ 95% CL



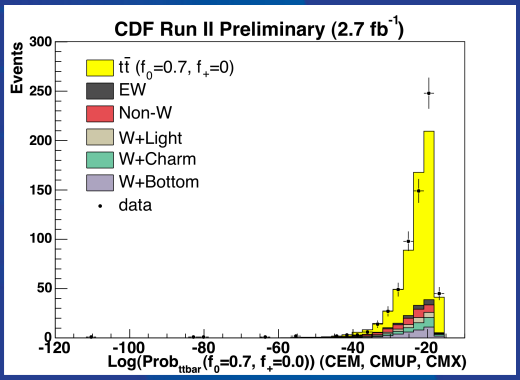
Spin correlations
of top-antitop



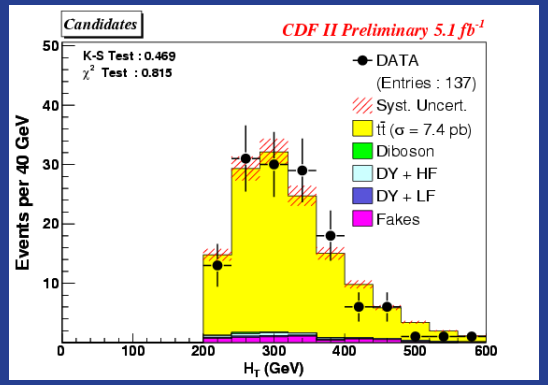
Top charge Q = 4/3
excluded @ 95% CL



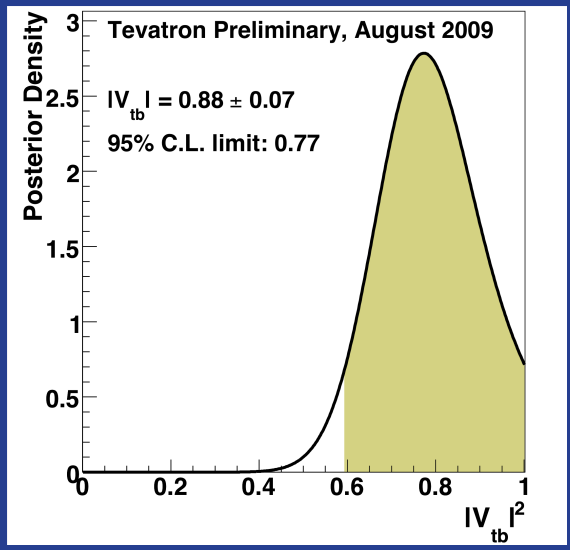
W helicity : SM f_0 = 0.7
Measured 0.88 ± 0.11 ± 0.06



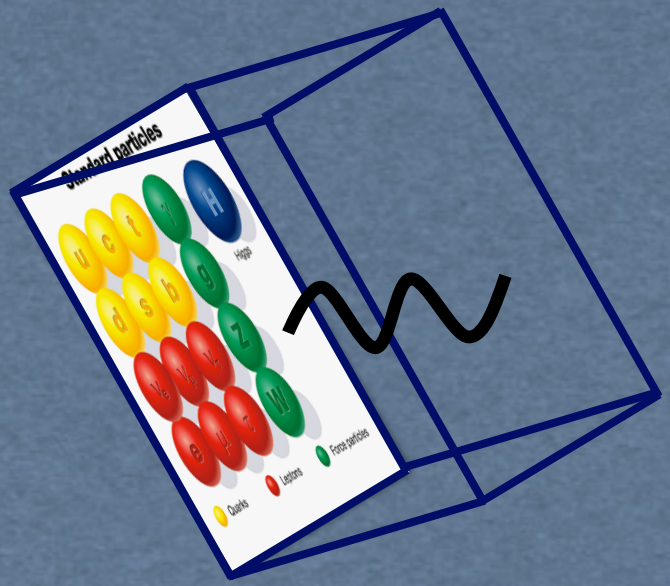
X-section tt dilepton mode :
$\sigma_{tt} = 0.7_{stat} + 0.5_{sys} + 0.4_{lum}$ pb

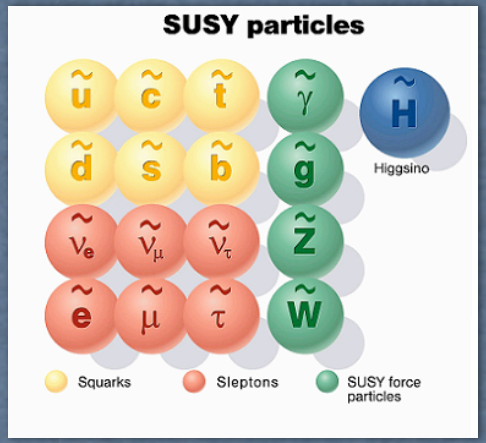


V_{tb} = 0.88 ± 0.07 pb (CDF+D0)



New particles beyond SM ?

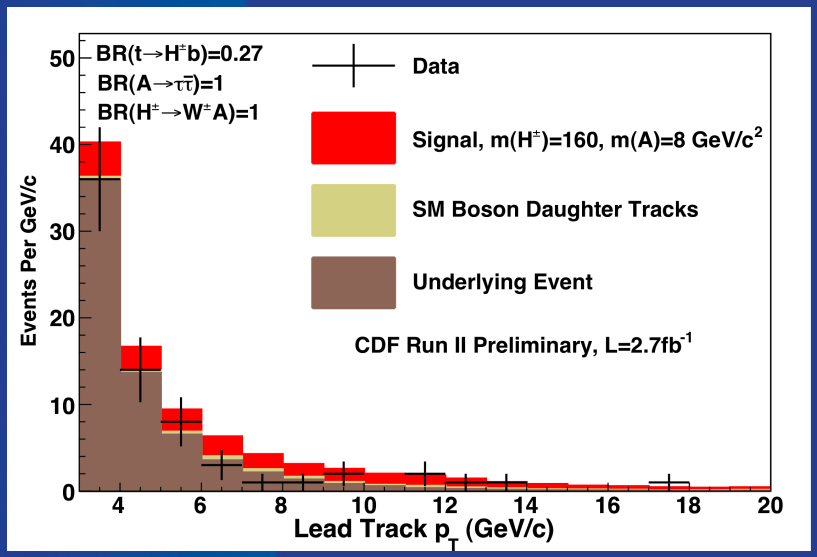




Extra-dimensions SUSY Dark Matter

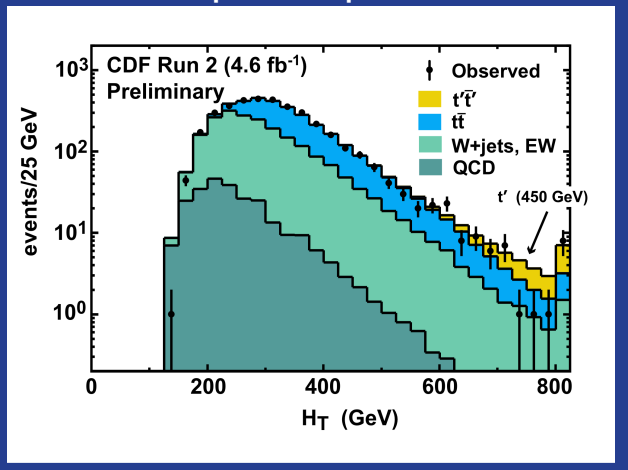
New particle searches with top quark

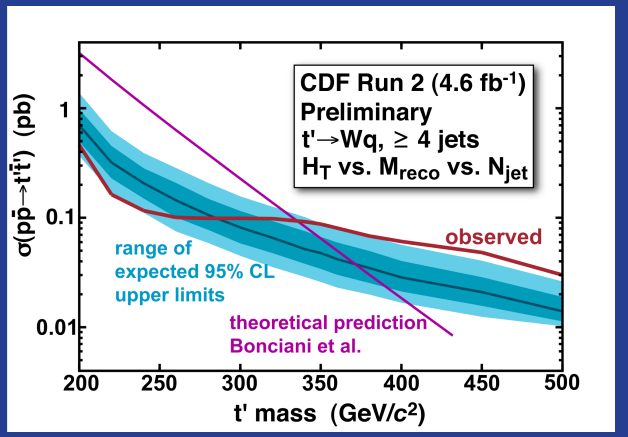
NMSSM $t \rightarrow H^+b \rightarrow W^+Ab$



- Next-to-Minimal MSSM predicts intermediate Higgs boson state
  - Leads to Extra taus in tt final state
  - Search for extra tracks from tau decay
- First limits set on previously unprobed physics model

t prime quark

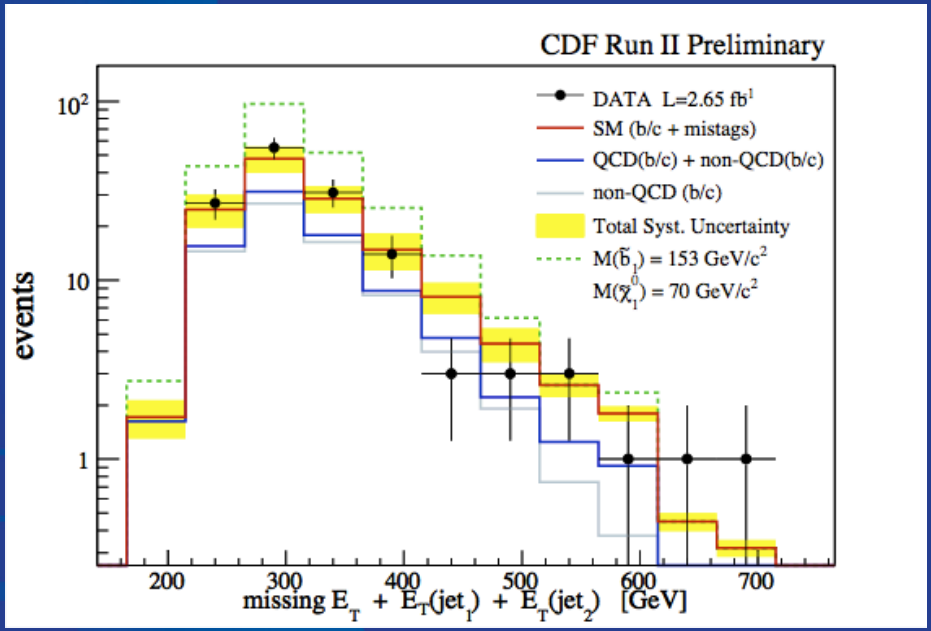


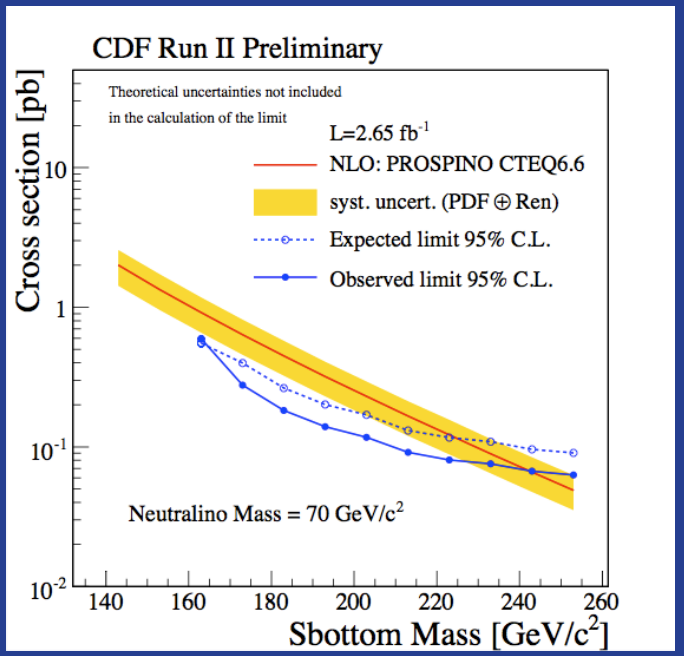


- 4th Generation of up-type quark decays like top quark
  - Some excess in tails
  - Exclude $m_{t'}$ up to 335 GeV

Search for squarks and gluinos

- SUSY Sbottom quark decays to b quark and neutralino (dark matter candidate)
  - Gluon fusion and quark annihilation production of SUSY particles means high rate !
  - Signature is two b-jets + MET

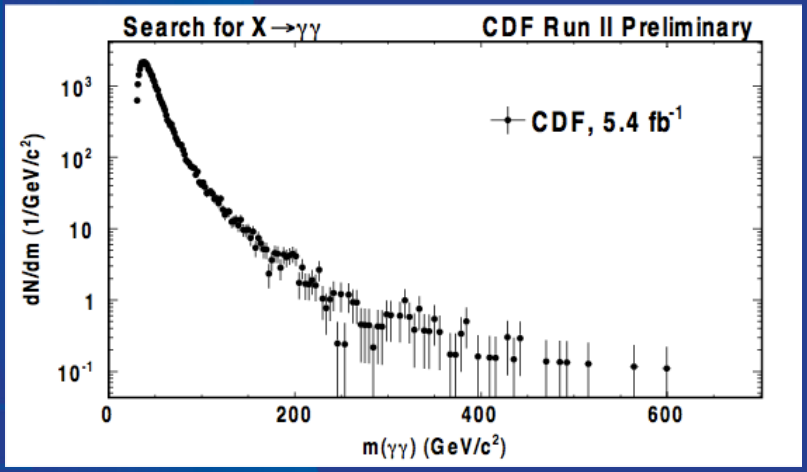


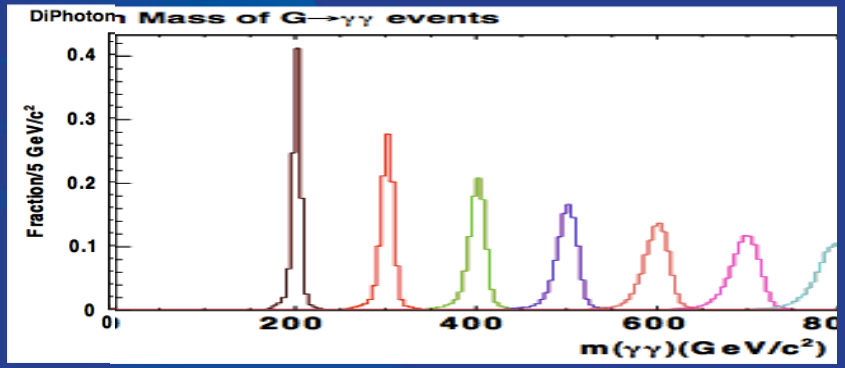


Sbottom masses excluded up to 230 GeV for neutralinos 40 - 80 GeV

Graviton search X → γγ

- TeV scale of electroweak phenomena determined by Planck scale through warped extra dimension
- Theoretically favored region when curvature of dimension is between 0.01 and 0.1 * Planck Scale
  - Graviton can be observed at TeV scale !

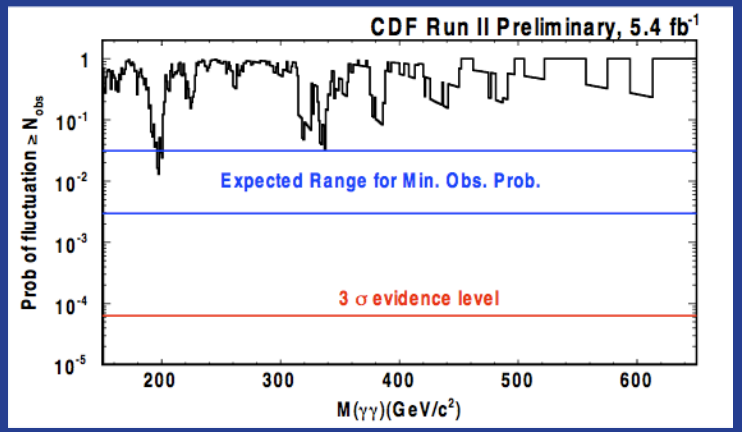




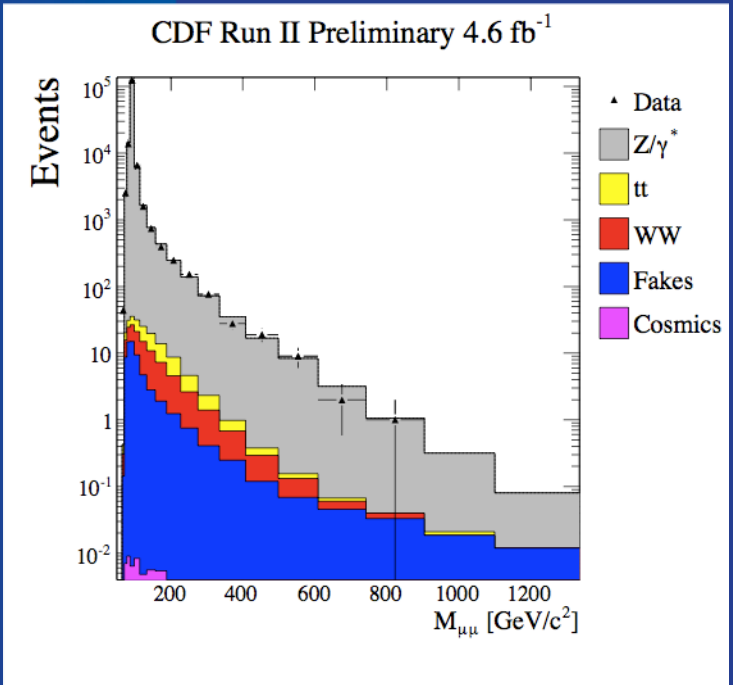
Result: RS Graviton excluded from 472 GeV to 976 GeV for favored region

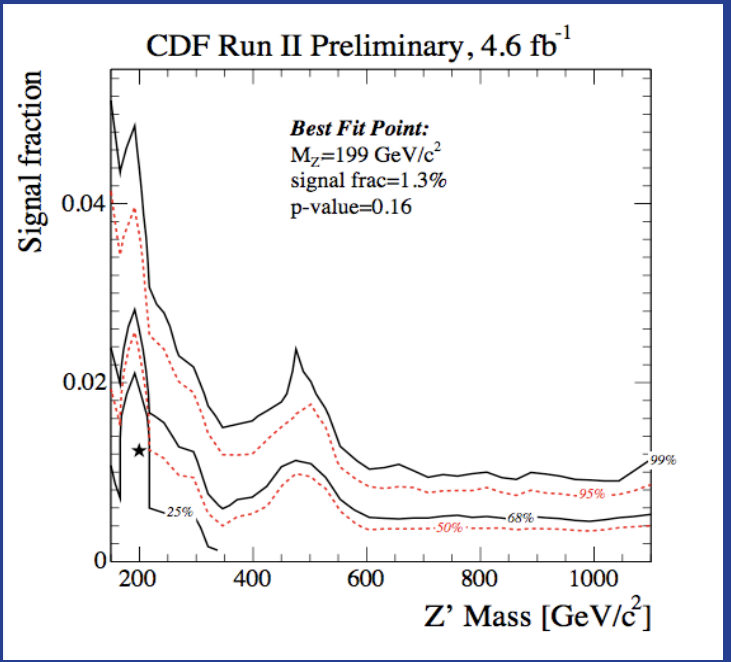
Most significant excess 200 GeV : P-value of 1.3%

Not significant when trials factor applied



Z Prime Search

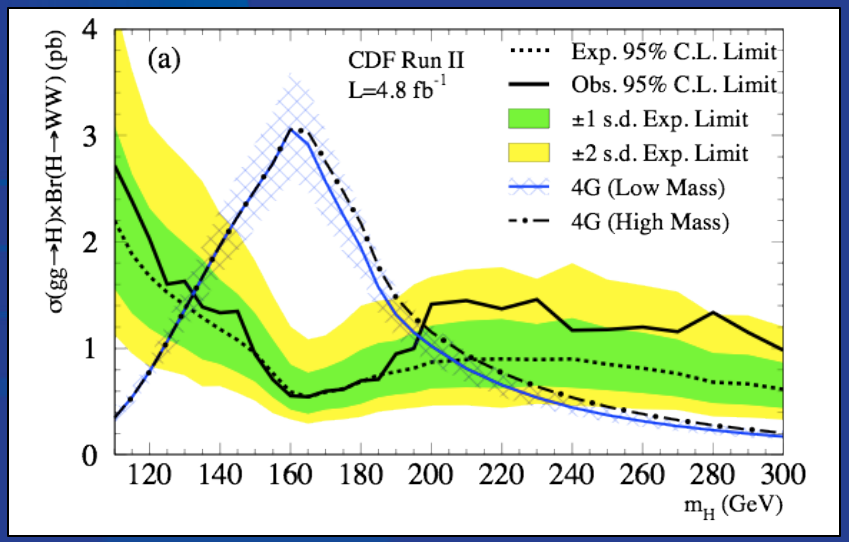




- Matrix element technique to probe Z→μμ final state
  - Angular information in addition to just $M_{\mu\mu}$: 20% gain
- Most significant deviation at 200 GeV P-value = 1.6%
- Z' excluded up to 1071 GeV !
  - ATLAS projects 200 pb^{-1} at 7 TeV to achieve similar sensitivity

Search for Higgs with 4 quark generations

- 4th quark generation popular theory to resolve SM discrepancies and produce new CP violation sources that could explain matter antimatter asymmetry of universe
- Analysis :
  - gg→H production enhanced if new 4th generation quarks more massive than top
  - Use existing H→WW analysis framework



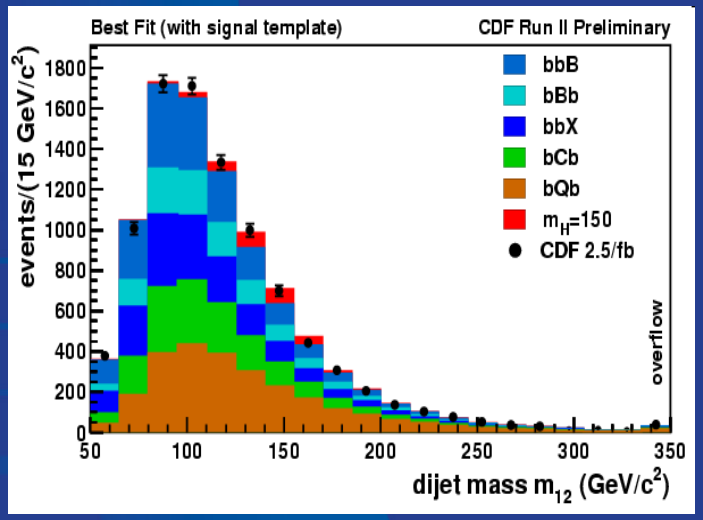
Excess could signal both evidence for Higgs boson, and evidence for 4th generation of quarks

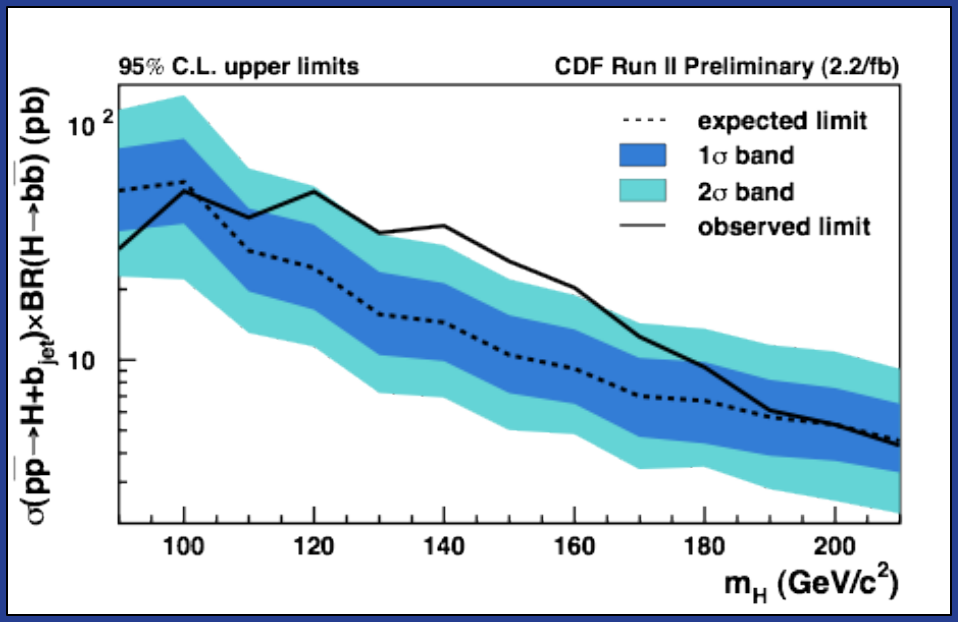
CDF + D0 combination :

$131 < m_H < 204$ GeV excluded

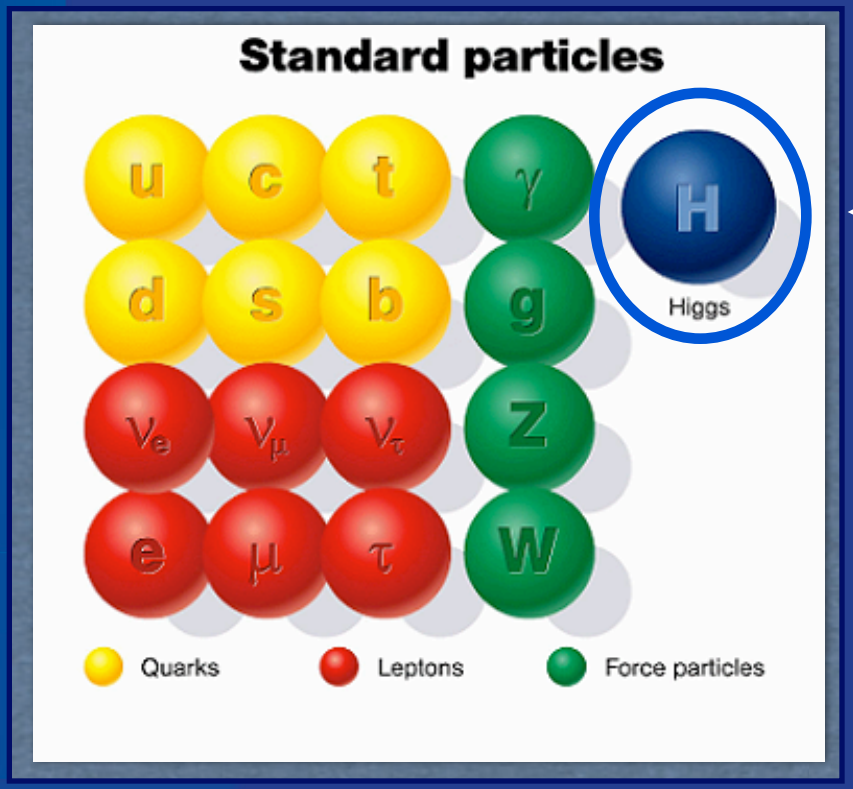
Search for Supersymmetric Higgs boson

- MSSM Higgs 3b search ($\Phi + b \rightarrow bb + b$)
  - Complements MSSM $H \rightarrow \tau\tau$ search
  - Relies on CDF's trigger-level b-tagging used in b physics
  - New version of analysis 2x more acceptance
    - m_H = 140 GeV most significant excess P-value = 0.9% (5.7% with trials factor)



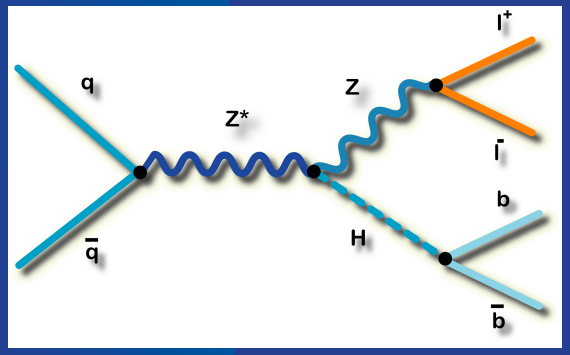


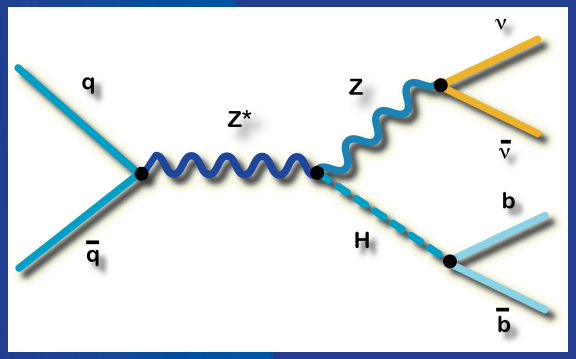
Is there a SM Higgs boson ?

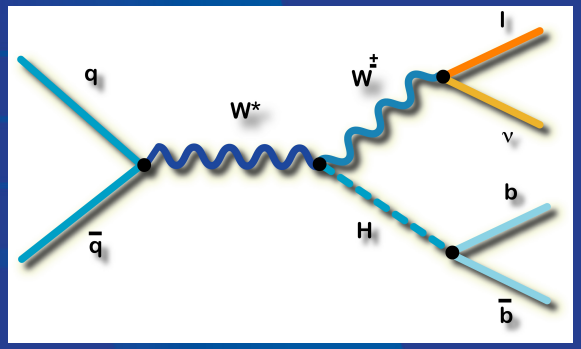


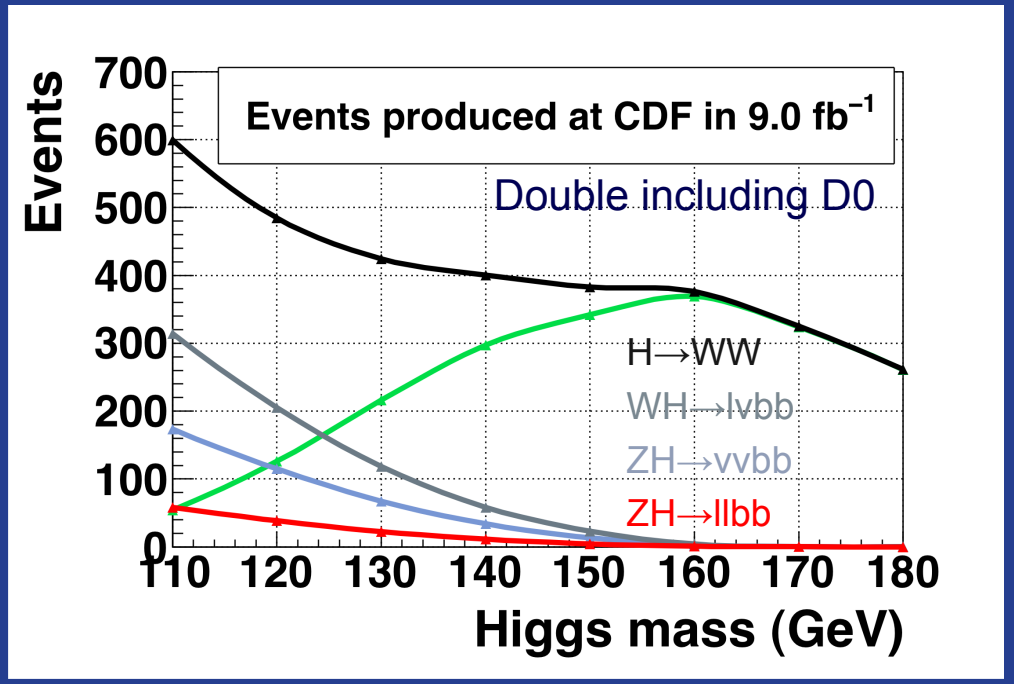
∃ ?

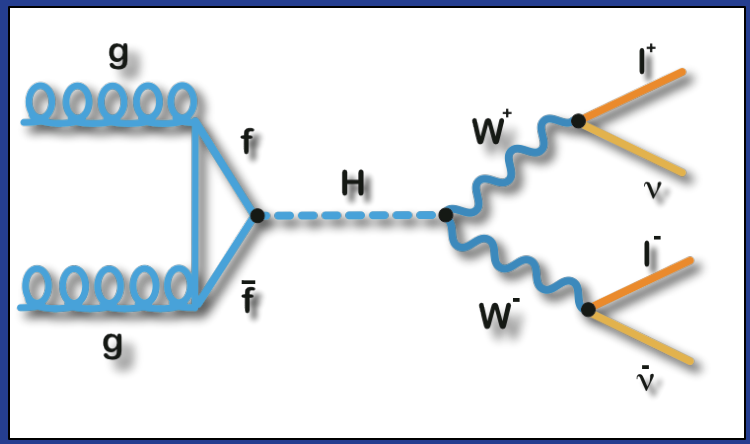
Higgs boson production and decay at the Tevatron





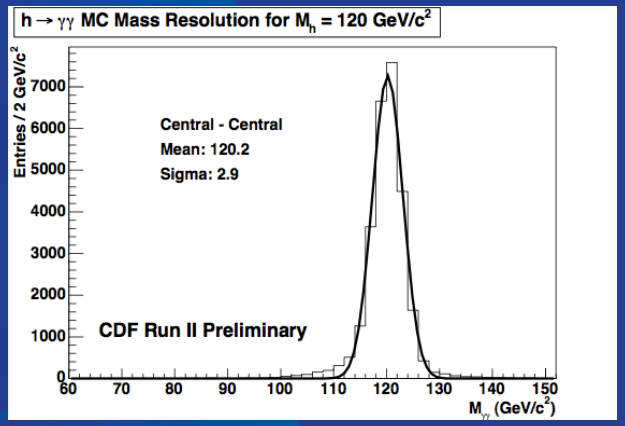


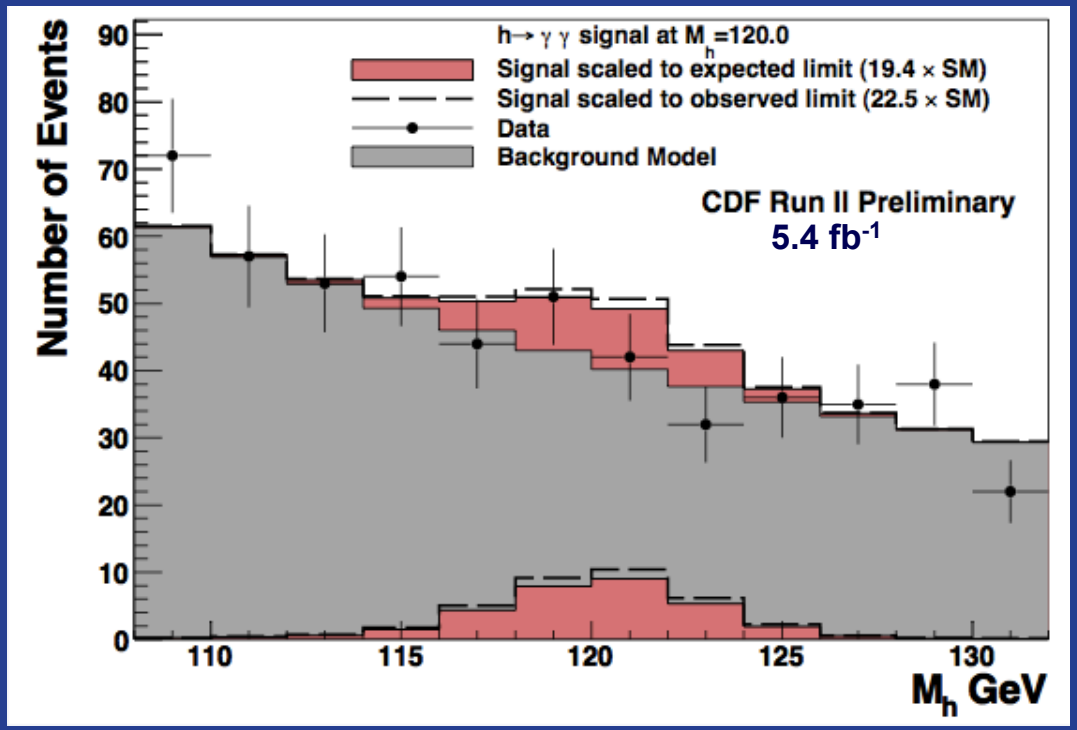




H→γγ

- New channel for 2010 ICHEP Higgs combination
  - Branching ratio small (0.2%) but excellent photon energy resolution

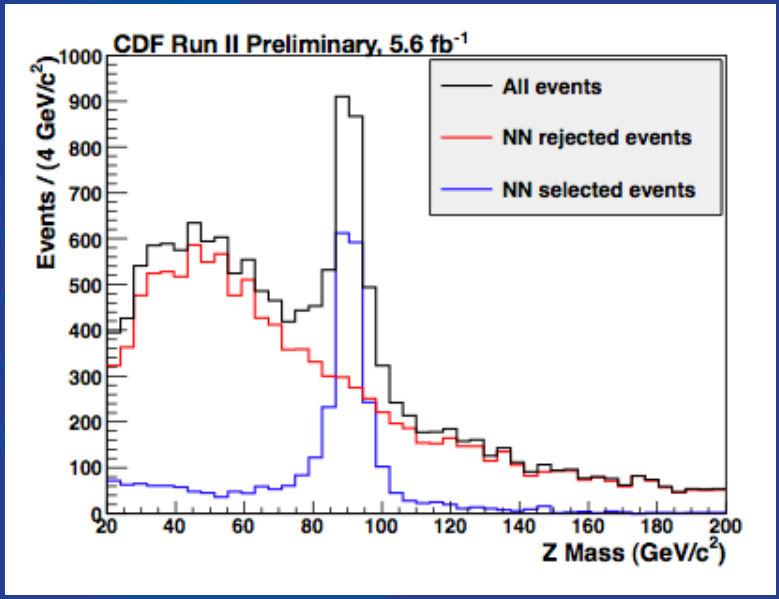




- $M_{\gamma\gamma}$ ~ 3 GeV
- Compare to 20 GeV for M_{bb}

ZH → track+track+bb

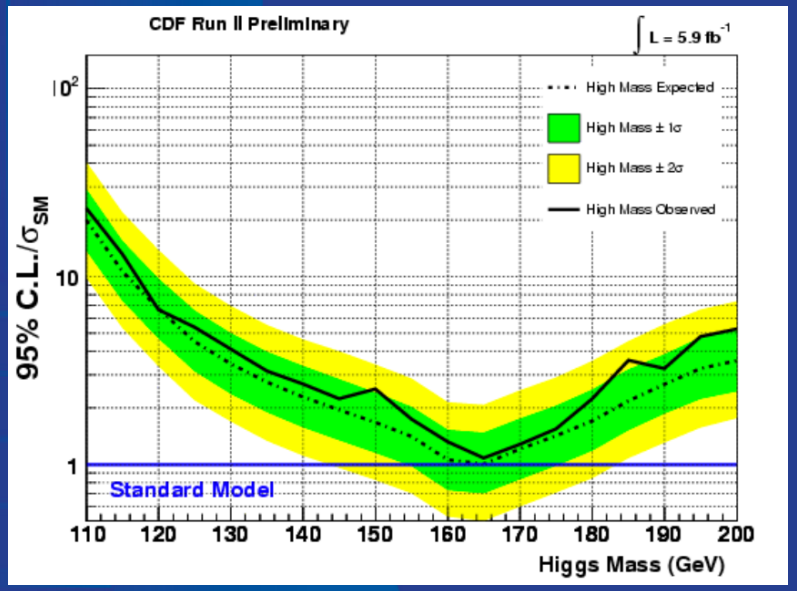
- New "channel" for 2010 ICHEP Higgs combination
  - Previously un-selected Higgs boson candidates in pp→Z*→ ZH
  - Recaptured ZH→μμ+bb candidates
    - Both muons fail loose muon ID
    - Captured on MET triggers as tracks with some parameters consistent with muons
      - Neural Network selection removes fake leptons

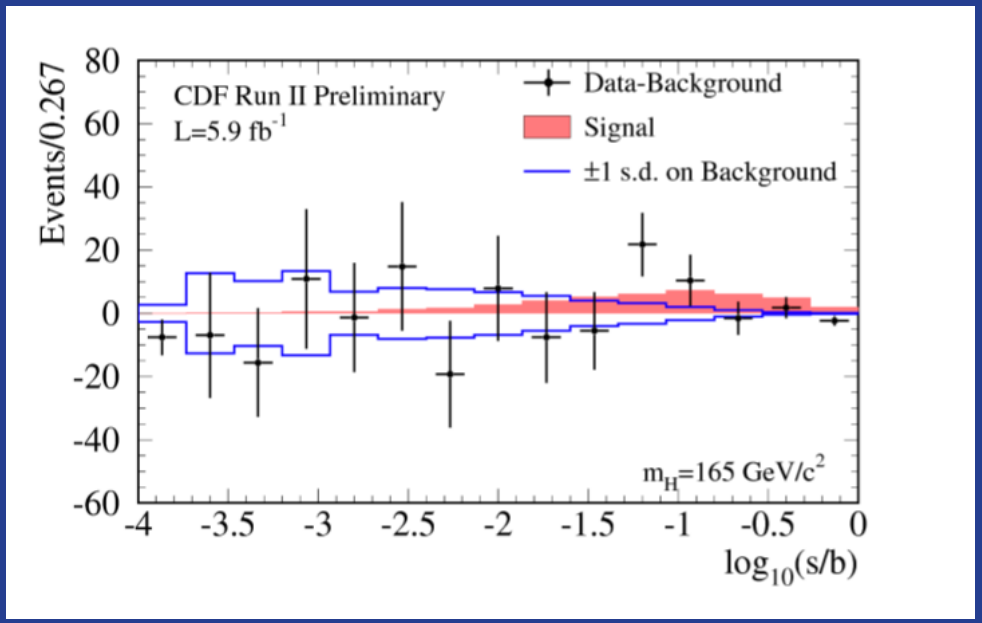


- Black shape = ~1300 real Z's on top 3000 fake Z's
  - Want to extract the real Z's
  - Can't handle large non-Z background
- Red shape = Neural Network muon selection removes non-Z fakes
- Blue shape = Nice Z peak used to search for Higgs

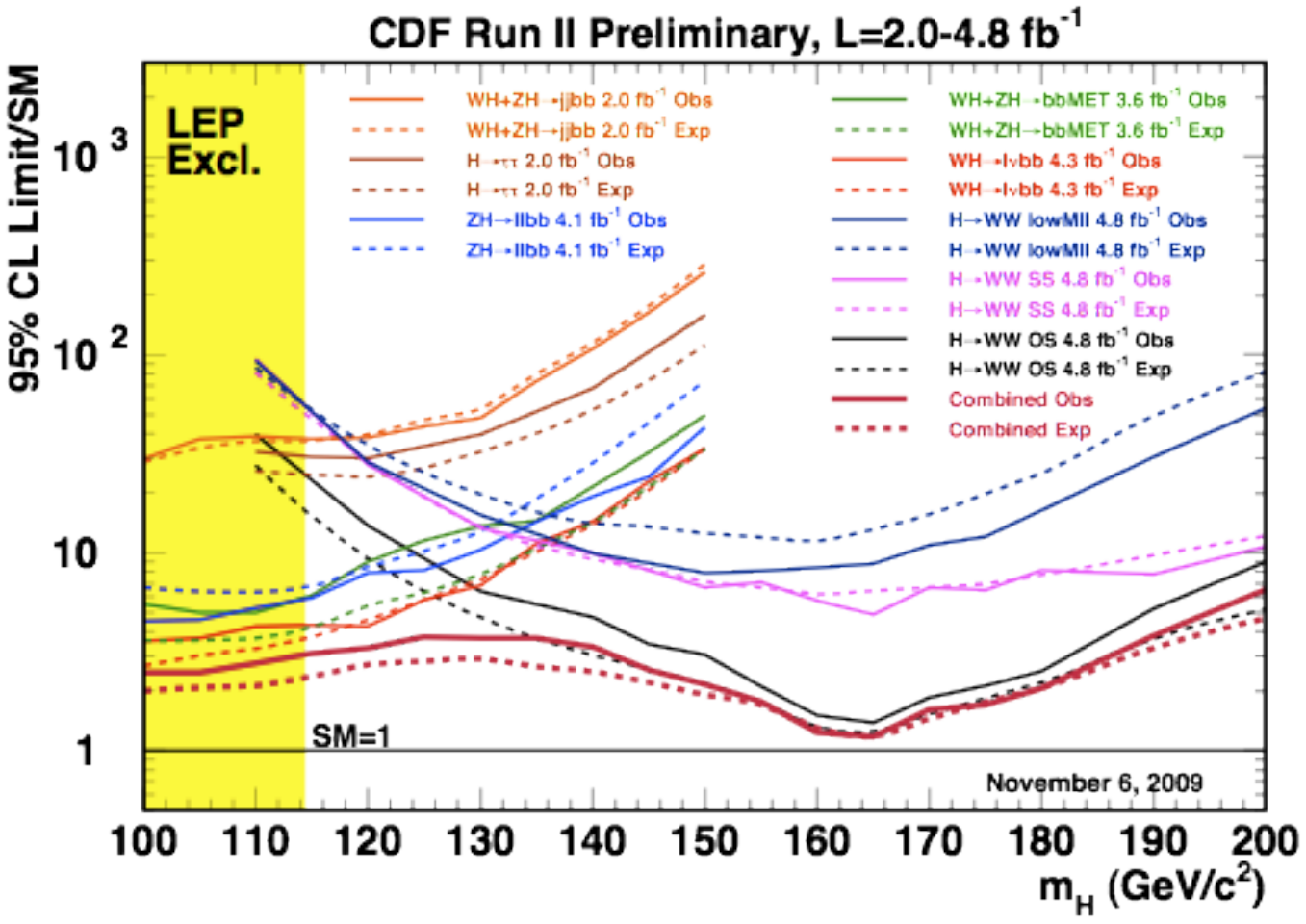
New High mass search ready for ICHEP

- 5.9 fb^{-1} analysis with many improvements
  - Achieves single experiment expected exclusion
  - Observed limit slightly higher 1.08*SM @ 165 GeV





CDF Combined Higgs search



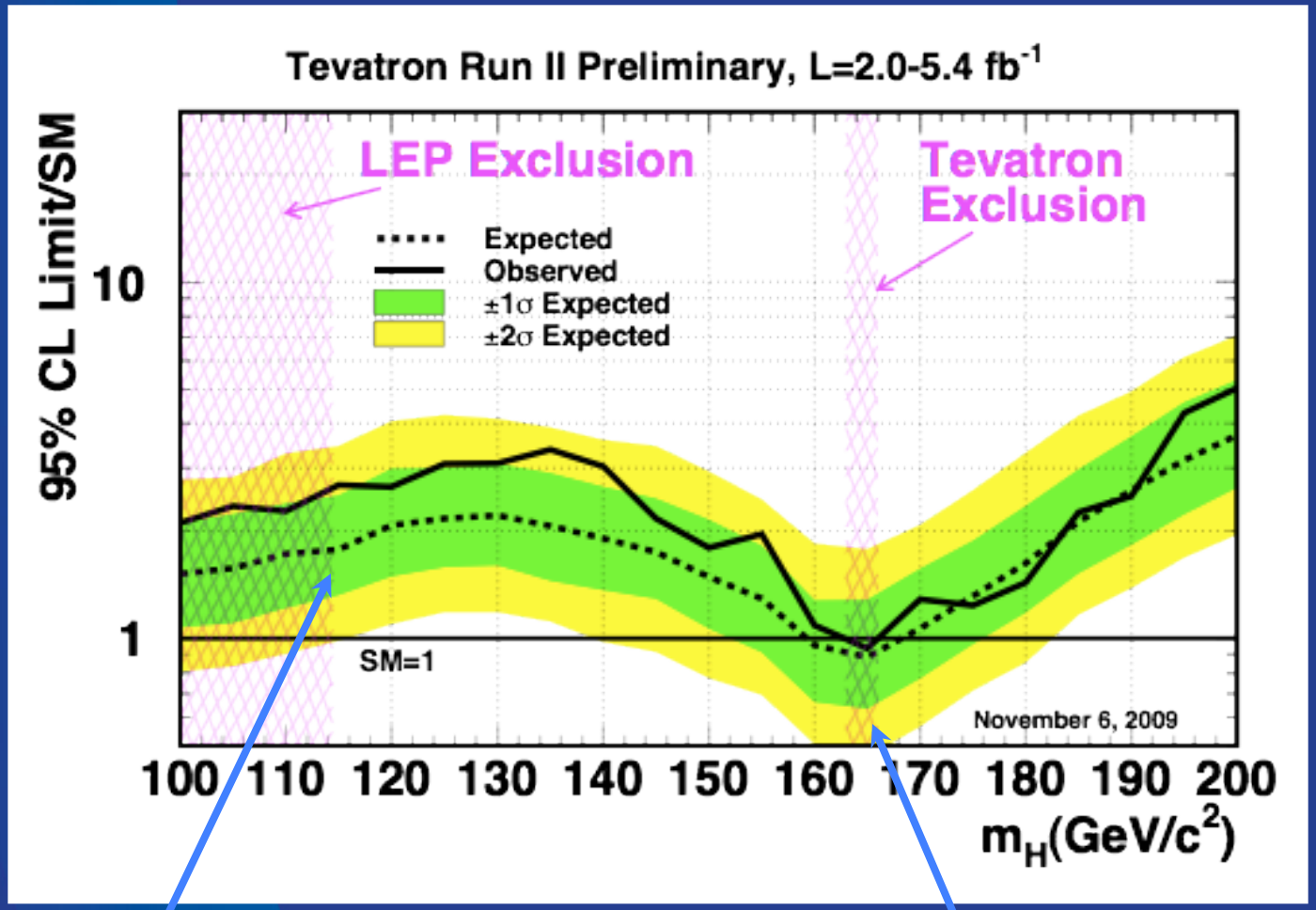
CDF combination from November 2009

Above does not include 4 new decay modes

New combination for ICHEP coming

Combined CDF & D0

New combination for ICHEP coming



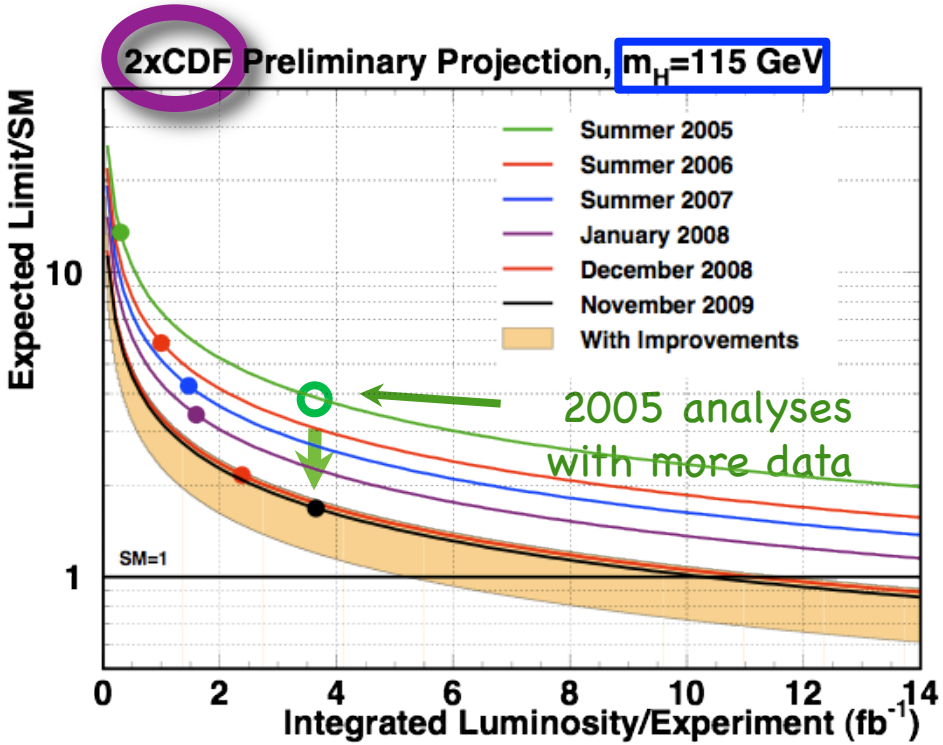
Systematic uncertainties correlated between experiments

Upper limit 2.7*SM
(1 σ excess)
Expected limit 1.8*SM

163 GeV < m_H < 166 GeV is excluded at 95% CL !
(Expected exclusion: 159 - 168 GeV)

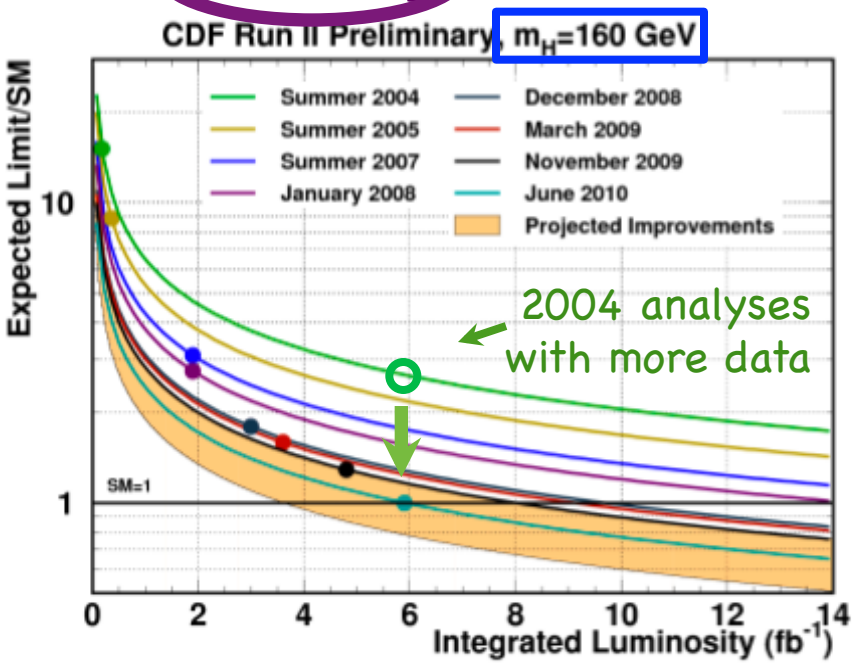
Past + Projections

- Steady improvements since 2004
  - Scale better than 1/sqrt(L) curves shown below



Low mass : updating for ICHEP

CDF only



High mass : Summer 2010 limits already well into yellow band

Plan to achieve low mass target sensitivity underway :

• Based on extra channels, secondary triggers, lepton ID efficiency improvements, new b-tagging algorithms, and improved background discrimination

Approaching target sensitivity

Prospects for Higgs evidence

~15 fb^{-1} :

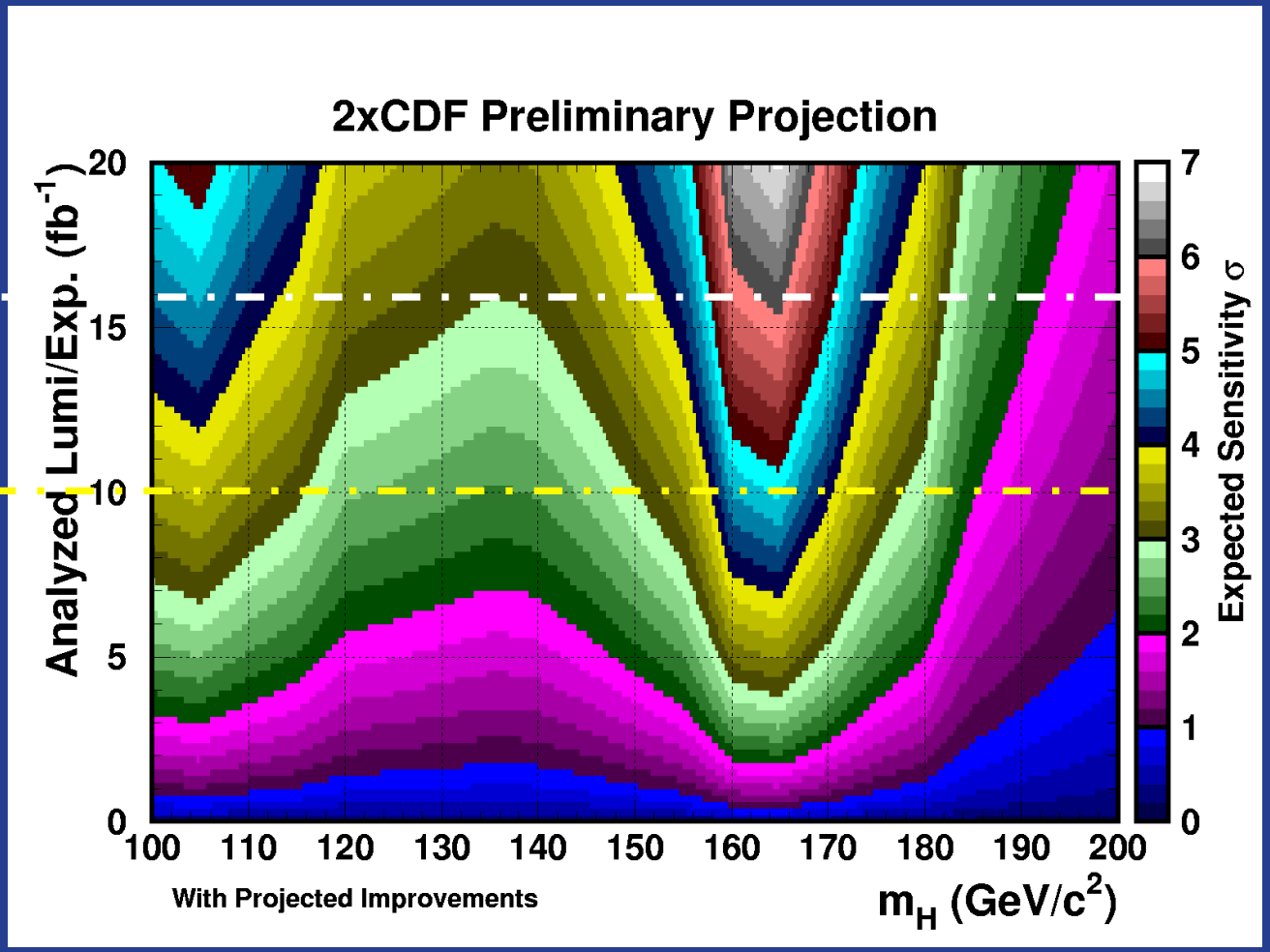
> 3 σ expected sensitivity from 100 – 180 GeV

4 σ @ 115 GeV

6 σ @ 165 GeV

End of 2011:

> 2.4 σ expected sensitivity across mass range



CDF's analysis plan for beyond 2011

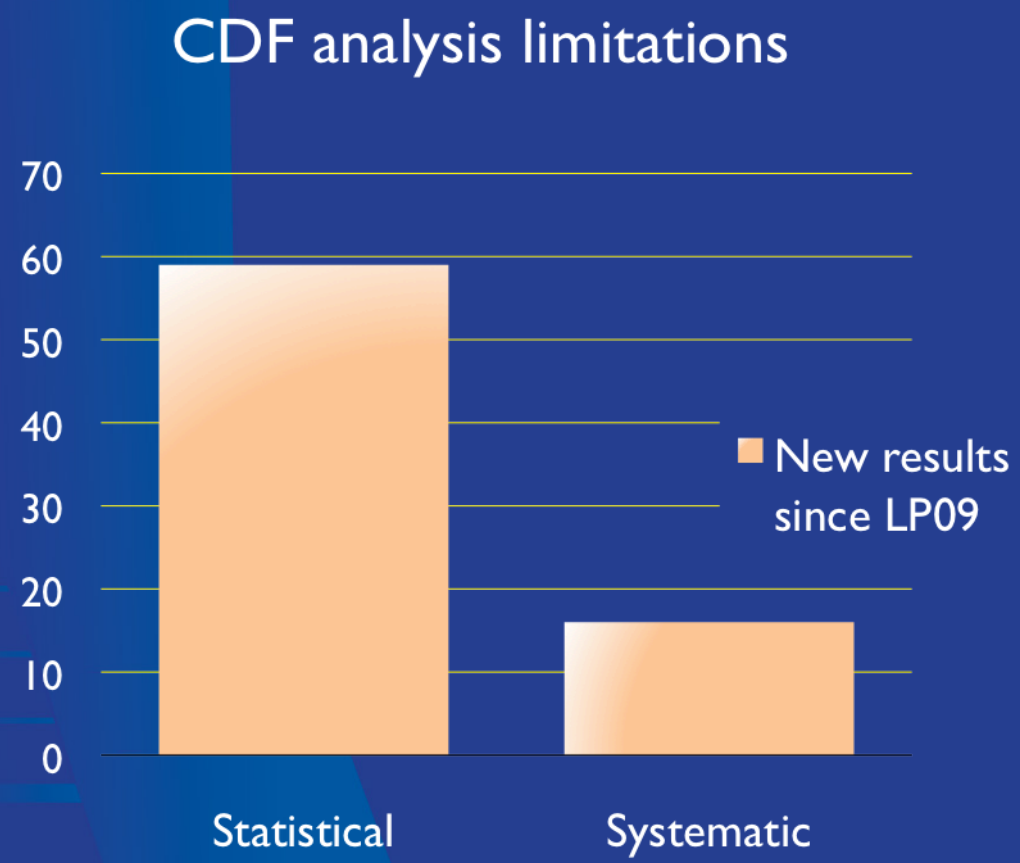
Final Run II analysis plan

- Aim to publish results using full Run 2 dataset no later than FY13
  - Detailed plan exists that covers “core” analyses
  - If we accomplish core, have tools to accomplish any analysis
  - Core requires 60 FTE, CDF currently estimates 120 (stud+pdoc) FTE in FY11-12
- To accomplish this plan we
  - Will maintain computing architecture and storage for 5 years after Run 2 ends
  - Benefit since vast majority of CDF analyses proceed from common ntuples so that tools can be readilty passed along to new students/pdocs
- Constraints
  - G&V and Computing budgets decreasing in FY11 and (significantly) in FY12
    - Will impact scientific effort, CPU, and storage resources available for analysis
    - Collectively will impact the speed with which these analyses can be accomplished
    - Current scenarios may eliminate possibility of reprocessing data set to take advantage of improvements in tracking and b-tagging algorithms
    - Working with the lab to try and mitigate these effects

Tevatron “Core Physics Program”

- Measurement of sin(2β_s); (8 FTE)
- Limit on the branching ratio of process Bs→ μ+μ-; (3 FTE)
- High precision measurement of W boson mass; (4 FTE)
- High precision measurement of top quark mass; (3 FTE)
- Measurement of single top production cross-section; (2 FTE)
- Higgs boson searches both in SM and SUSY scenarios; (25 FTE)
- SUSY searches in "golden" mode Gaugino-neutralino with tri-leptons; (3 FTE)
- SUSY searches in “golden” mode Squark-gluino with multijets plus missing transverse energy; (3 FTE)
- Searches for high mass resonances in the e+e-, μ+μ-, γγ and jet-jet invariant mass spectra (sensitive to Large Extra dimensions, Z' and other processes not present in the Standard Model); (6 FTE)

CDF analysis limitations



- Majority of our analyses are statistically limited
  - Not difficult precision measurements
- Can be improved by :
  - Additional data
  - Improved analysis techniques
- Same profile for Core analyses

Fermilab scientific staff on CDF

- Fermilab is 15% of CDF author list
- Leadership
  - Spokesperson : Rob Roser
  - Higgs Physics Conveners : BJK and Eric James
  - QCD Physics Convener : Sasha Pronko
  - B Physics Convener : Diego Tonelli
  - Offline heads : Rick Snider and now Ray Culbertson
  - Operations head : Phil Schlabach
- Physics output
  - Fermilab staff primary authors on 52% of 75 new physics results

Conclusions

- CDF is asking many of the most important questions of particle physics
  - Getting answers which propel the field
    - Powerhouse of results in recent years
  - Possible hints to non-SM physics could get more exciting
- Higgs effort stronger than ever
- Collaboration is smaller, but output is high
  - # papers 2009 + 2010 = 2005 + 2006 + 2007 + 2008

- Expect to be competitive with LHC for several years after running
  - Plan for publishing core results within two years

Backups

CDF

- Need large dataset
  - Tevatron has delivered 9 fb^{-1}
  - 6 fb^{-1} data up to March 2010 shown today
- Need excellent detector
  - Silicon tracker (SVX)
    - $|\eta| < 2$, 90 cm long, r_{L00} = 1.3 – 1.6 cm
  - Drift Chamber (COT) ***EXCELLENT TRACKING***
    - 96 layers, between 44 and 132 cm
  - Muon coverage
    - $|\eta| < 1.5$ ***TRIGGERED TO 1.5 GeV/c***
    - outer chambers high purity muons
  - Electron, general calorimeter
    - $|\eta| < 2.8, 3.5$
  - Triggers ***CAN FIND LEPTONS IN COVERAGE GAPS***
    - e, μ, τ, 2nd Vtx, MET, jets

GLOBAL TRACKING, CALORIMETER & B-HADRON ID AT HARDWARE TRIGGER LEVEL